3. 1. 2. 2 RFQ

Cavity structure

The construction methods of the 30mA- and 50mA-RFQ cavities are different, since the design beam currents and the maximum design RF duty factors (3% for the 30mA-RFQ and 15% for the 50mA-RFQ) are different. FIG 3.1.2.2.1 and FIG 3.1.2.2.2 show schematic drawings of the side views and cross sectional views of the RFQs, respectively.

The 30mA-RFQ is designed with a rather short vane length (3.115 m) for a rather high ejection energy (3 MeV) by optimizing the cell parameters with the design code KEKRFQ [1]. This short length makes it possible to compose the 30mA-RFQ cavity as a longitudinally one cavity. As shown in FIG 3.1.2.2.2, the cavity is divided into four quadrants in the cross-sectional plane. Each quadrant was cut out from a 0.2% silver doped oxygen-free copper (OFC) pillar. The cavity is assembled by bolting the four quadrants together. An RF-contactor is inserted between the two neighboring quadrants. Since the whole cavity is installed in a large vacuum chamber, the cavity itself has no vacuum sealing. The 30mA-RFQ has 16 RF-field pick-up monitors, 14 fixed stab-tuners with vacuum ports, 6 movable stab-tuners and 2 RF-couplers at two different longitudinal positions. The resonant frequency during the operation is tuned by changing the positions of the movable stab-tuners.

In order to achieve a design beam current of 50 mA, the longer vane length (3.874 m) than that of the 30mA-RFQ is necessary for the 50mA-RFQ. It is quite difficult to cut out the vanes with high accuracies from whole length pillars. Therefore, the cavity is divided longitudinally into three modules. The lengths of the first, second and third modules are 1.3041 m, 1.2665 m and 1.3034 m, respectively. Each module consists of four peaces and it is assembled by means of a laser welding method. The weld seals both of the RF-contact and the vacuum. The material of each cavity is pure OFC. Three modules and end plates are bolted together and Helicoflex type metal O-rings are used as the RF-contactor and the ordinary metal O-rings seal the vacuum. The 50mA-RFQ is equipped with 24 RF-field pick-up monitors, 30 fixed stab-tuners with vacuum ports, and 2 RF-couplers at two different longitudinal positions. The resonant frequency during operation will be tuned by controlling the temperature of the vane cooling water. The principle of this system is same as that of the SNS-RFQ [2].

For both the RFQs, π-mode stabilizing loops (PISLs) [3,4], which invented in the development of the JHP-RFQ [5], are employed in order to stabilize the accelerating mode against a dipole mode mixing. The 30mA-RFQ has 14 pairs of PISLs and the 50mA-RFQ has 20 pairs of them. The intervals between the horizontal and vertical PISLs are 215 mm for the 30mA-RFQ and 210 mm for the 50mA-RFQ.

The inside-dimensions of the cavities were determined based on the SUPERFISH [6] and MAFIA [7] calculations. The results of the calculations are summarized in Table 3.1.2.2.1. The absolute values of the design frequencies were derived from the SUPERFISH results by taking the effect of the PISLs into account. The frequency shifts between with and without the PISLs were estimated with two different MAFIA calculations (with and without PISLs).

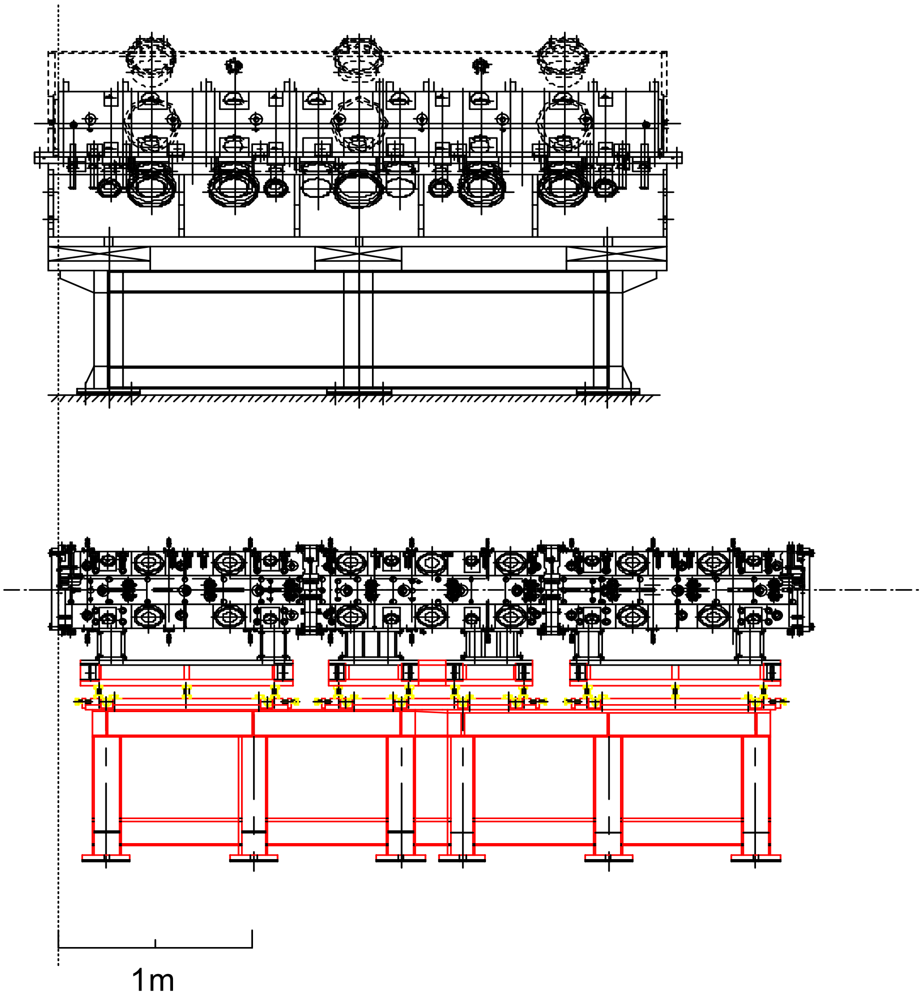

FIG 3.1.2.2.1 Schematic view of the RFQs. Upper: drawing of the 30mA-RFQ. Lower: conceptual design of the 50mA-RFQ.

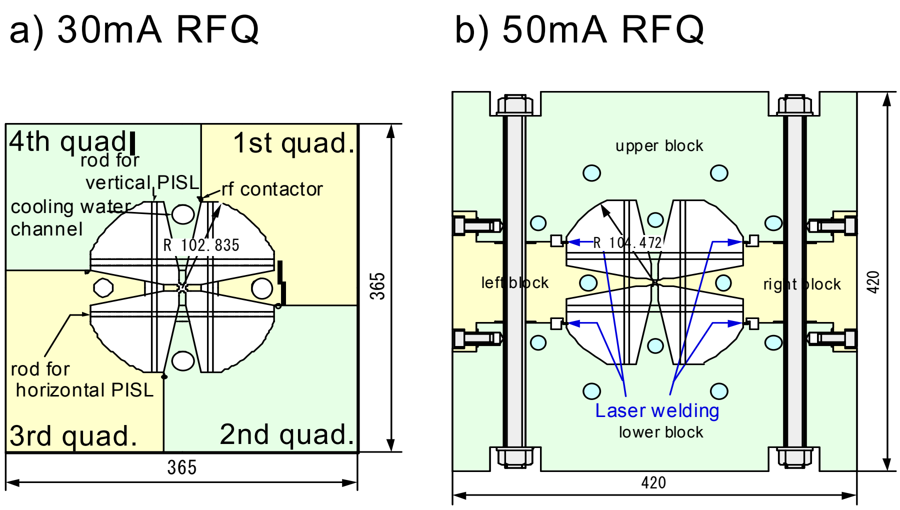

FIG 3.1.2.2.2 Cross sectional views of the 30mA- and 50mA-RFQs. The 30mA-RFQ is assembled with the bolts. The 50mA-RFQ is fabricated by means of the laser welding method. Bolts in the figure are used for mechanical supports.

Table 3.1.2.2.1 Summary of the SUPERFISH and MAFIA results.

	30mA	50mA
SUPERFISH frequency: f_{SF} (MHz)	333.827	334.444
Q-value: Q_{SF}	11276	11403
Power dissipation: P_{SF} (kW)	243	317
MAFIA frequency without PISL: f_{MFWOP} (MHz)	330.675	332.867
Q-value: Q_{MFWOP}	10812	11067
MAFIA frequency with PISL: f_{MFWP} (MHz)	320.782	322.412
Q-value: Q_{MFWP}	10264	11577
f_{MFWOP}- f_{MFWP}: Δf_{MF} (MHz)	9.893	10.455
Design frequency (f_{SF}- Δf_{MF})	323.934	323.989

Test results of the 30mA-RFQ

Low-power RF-measurement and tuning of the 30mA-RFQ have been done. Details of the measurements are described in ref. [8]. At first, both the longitudinal and azimuthal field distributions were tuned with low-power stub tuners, and the resonant frequency was also tuned to be 323.9 MHz, which is equivalent to 324.0 MHz in the vacuum. The uniformity of the field distributions was within 0.6%. The measured unloaded Q-value of the cavity was 8960, which was 79% of the SUPERFISH calculation. The frequency separation between the accelerating mode and the nearest dipole mode was 19.1 MHz[1]. Finally, the couplings of two input couplers were tuned to be 1.4. The shapes of the high-power stab-tuners, RF-couplers and end plates were determined by using the data of the low-power measurements.

Table 3.1.2.2.2 Measured low-power RF-characteristics of the 30mA-RFQ.

Frequency	323.9 MHz (equivalent to 324MHz in the vacuum)
Q-value	8960
Field uniformity	<0.6 %
Dipole mode separation	19.1 MHz

The high RF-power conditioning of the cavity was started with a pulse duration of 20 μsec and a repetition rate of 50 Hz. After 45 hours of the conditioning, the peak power was reached to 405 kW with this duty factor, as shown in FIG 3.1.2.2.3. This conditioning process is much smoother than that of the JHP-RFQ [9]. One reason of this is careful treatment of the inner surface of the cavity, such as acid rinsing and chromate treatment. With additional 17 hours conditioning, the design duty factor (600 μsec and 50 Hz) with 405 kW rf power was achieved by increasing the pulse duration. Even after the design duty factor was achieved, the conditioning was continued by swinging the rf power from almost 0 kW to 405 kW to reduce an outgassing from the inner surface of the cavity.

[1] This value is different from that in ref. [8], since a missing dipole mode was observed after the publication.

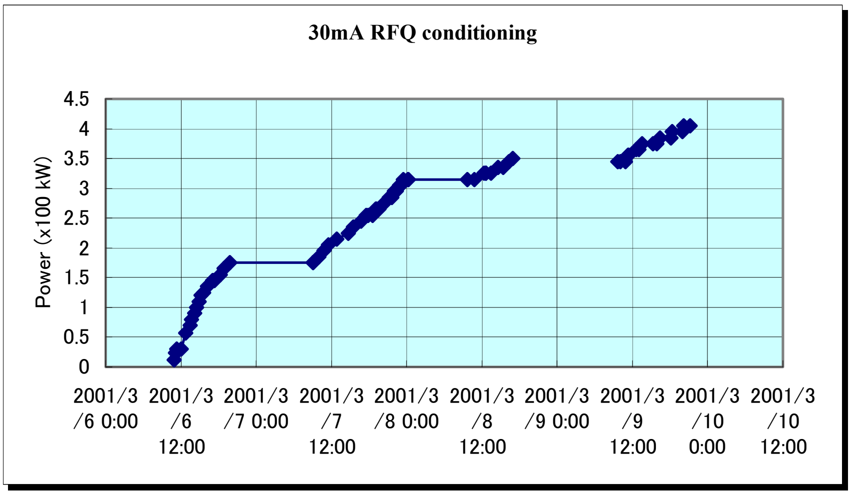

FIG. 3.1.2.2.3 History of the conditioning of the 30mA-RFQ with the 20 μsec duration and 50 Hz repetition. The horizontal axis represents a real time.

Finally, a beam from the LEBT was injected. The ejection current from the RFQ was 9.7 mA when the injected beam current was 10.4 mA, thus the transmission was 93%. A beam diagnostic device, which was the same one as described in ref. [4], was used to analyze the extracted beam from the RFQ. Measured transverse emittances of an 11mA beam are shown in FIG 3.1.2.2.4. The power dissipation was measured to be 305 kW at the operating point, which corresponds to 1.3 times as large as the SUPERFISH calculation listed in Table 3.1.2.2.1. From this value, the power dissipation of the 50mA-RFQ is estimated to be 380 kW (305 kW×3.874/3.115).

Status of developments of the 50mA-RFQ cavity

The first module of the 50mA-RFQ is now under construction. In addition, a cold model has been built to investigate a deformation due to the laser welding. The length of the cold model was 675 mm. The measured resonant frequency of the TE_{210} mode after the laser welding was 325.190 MHz, which is 570 kHz lower than a SUPERFISH calculation. The Q-value was measured to be 8174 (79% of the SUPERFISH calculation)

FIG 3.1.2.2.5 shows the field distributions of the cold model after the laser welding measured with a bead perturbation method. Top figure is the distributions without any tuning. This shows that there is a large unbalance of the field strength between the upper two quadrants and the lower ones of the cavity. In this cold model, the vane position errors of several tens of μm could cause a dipole mode mixing, because the separation between the quadrupole mode and the dipole mode is only 2 MHz. The bottom figure of FIG 3.1.2.2.5 shows the distributions after the tuning using with stub tuners of the lower two quadrants. The frequency shift before and after the tuning was 184 kHz, which corresponds to the inter-vane distance error of 18μm. The errors of the vane position from a direct measurement were within 30μm. These errors are sufficiently small to build our RFQ cavity.

References

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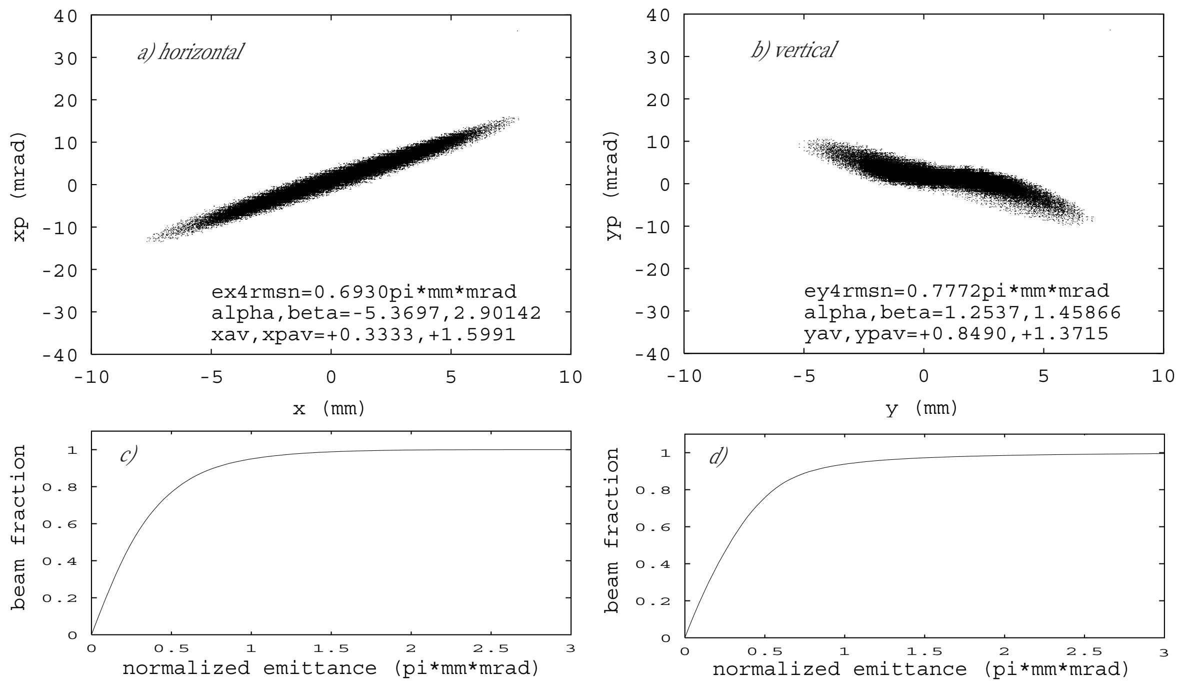

FIG. 3.1.2.2.4 Measured emittances of the 11mA beam extracted from the 30mA-RFQ. The a) and b) represent the horizontal emittance (α_x=5.370, β_x=2.901 mm/mrad $e_{x,4rms,n}$=0.693 π·mm·mrad) and the relationship between the normalized emittance and the beam fraction. The c) and d) represent the vertical emittance (α_y=1.254, β_y=1.459 mm/mrad $e_{y,4rms,n}$=0.777 π·mm·mrad) and the relationship between the normalized emittance and the beam fraction.

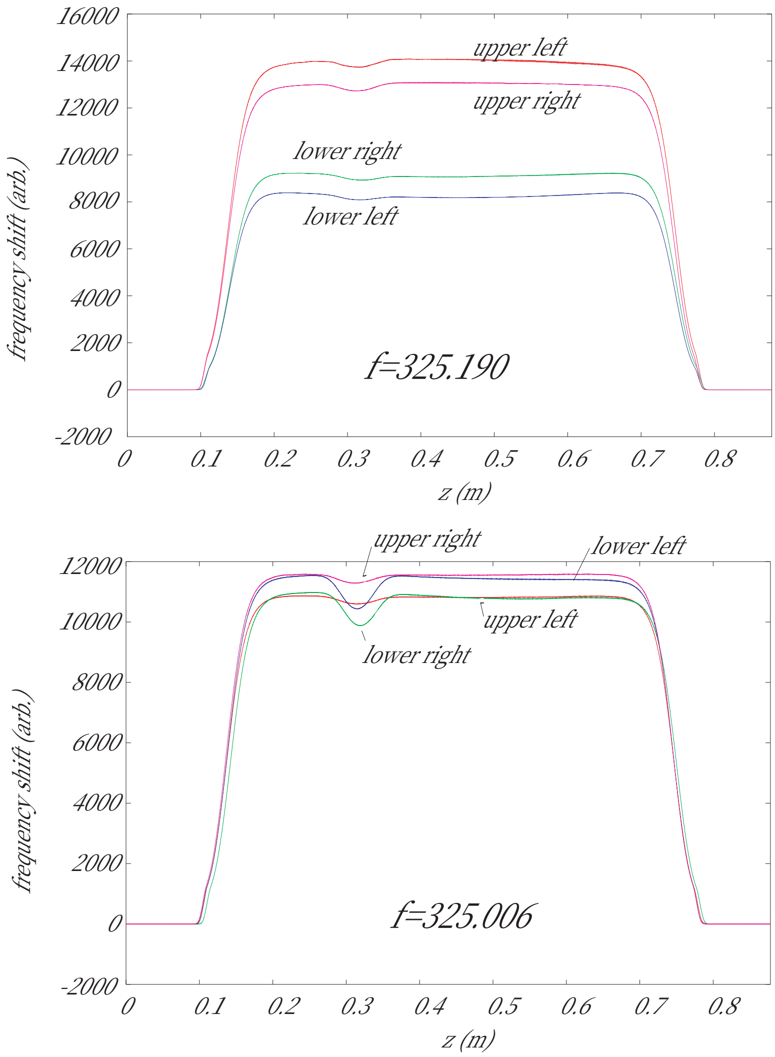

FIG. 3.1.2.2.5 Measured field distributions of the cold model after the laser welding. Top figure shows the distributions before the tuning, and bottom figure represents the distributions after the tuning with stub tuners of the lower two quadrants. The resonant frequencies were 325.190 MHz and 325.006 MHz, respectively.